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IONOSPHERE INVESTIGATIONS

by

Ya.L. Al'pert

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Ya.L. Al'pert

SUMMARY

This brief review paper describes the ionosphere as a whole, sums up the achievements in this field and the bearing the studies, made to date, have on radio communications and on solar terrestrial relationships.

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The study of the ionosphere plays an important role in problems concerned with solar and terrestrial physics. According to our present interpretation the term ionosphere of the Earth, is used to designate the area of near-Earth plasma extending directly from the surface of the Earth (at altitudes $\underline{z}$ of about 50-60 km) to distances of 20,000 to 25,000 km from the Earth.

The processes taking place in the ionosphere are controlled by wave and corpuscular streams emanating from the Sun. At the base of the ionosphere, where the D-region is formed (z $\sim$ 50-80 km), X-ray and ultraviolet (UV) radiation from the Sun play the principal role. Higher, in the so-called E-layer (z $\sim$ 85-150 km) up to the maximum of the F-region of the ionosphere (z $\sim$ 250-400 km), together with UV solar radiation corpuscular streams falling on the Earth, especially during periods of high solar activity, gradually begin to exert a strong effect on the structure and processes of the ionosphere. These streams play a particularly important role in the outer ionosphere, namely above its main maximum. Here, the concentration of neutral particles decreases rapidly with altitude and the energy density of charged particles $N_0 \varkappa T$, as we approach the limits of the ionosphere, gradually begins to satisfy the equality $N_0 \varkappa T \sim N_{cor} \frac{M v_0^2}{2}$ (where No is the electron concentration, κ is Boltzmann's constant, T is the temperature, v_0 is the flux velocity), i.e. this energy density becomes equal to the energy density of the incident flux of charged particles.

In the outer ionosphere the effect of the Earth's magnetic field is also assuming a steadily growing importance. The energy

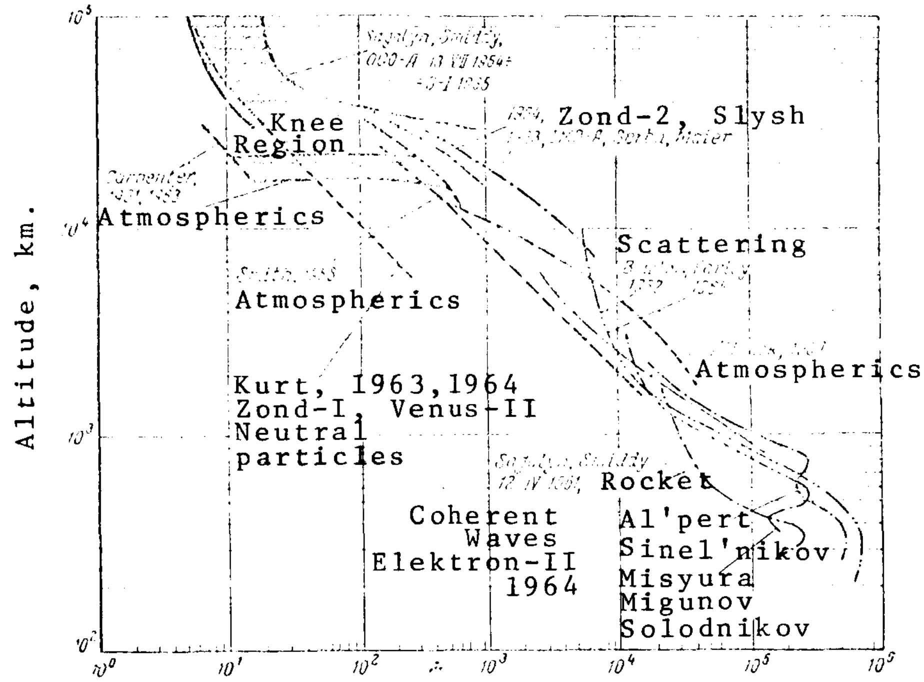

Fig.I.

Concentration of Charged Particles

density of this field, $H_0^2/8\pi$, is much higher than $N_0\kappa T$ everywhere in the ionosphere. However, with a decrease in the pressure of neutral gas and in the number of collisions between charged particles the effect of charge precession around magnetic lines of force and of particle drift on the structure of the ionosphere increases, and various types of plasma instability and resonances exert a stronger effect. As a result, elongated inhomogenous formations arising in the ionosphere along the lines of force of the magnetic field, become a substantial element of its structure. Low frequency plasma oscillations and various types of waves appearing in the plasma under the action of solar fluxes and of different types of electromagnetic waves incident on the ionosphere, as well as wave packets moving along magnetic lines of force, become one of the main features characterizing the outer ionosphere.

To summarize we can say that the state of the outer ionosphere and its structure are to a considerable extent controlled by the magnetic field of the Earth, by the particle fluxes emanating from the Sun and falling on Earth, and by plasma oscillations. These characteristics are particularly clearly expressed during periods of increased solar activity, namely of sporadic eruptions from the surface of the Sun. Insofar as the terrestrial ionosphere acts as a sort of a window through which an observer located on the ground and in its immediate vicinity "looks" at the Sun, it is clear how big a role do the properties of this window play in its study. And, vice-versa, we may see how important it is to have the appropriate information on the properties and character of radiation emanating from the Sun in studying the structure of the ionosphere and the phenomena taking place in this region.

Naturally, the combined solution of these problems is of very great practical significance for the design of radio communications and radio navigation systems near the Earth, for calculations of cosmic radio communication, and for selecting more favorable and less hazardous flight conditions for astronauts.

The possibilities of carrying out experimental studies of the ionosphere have been greatly expanded during the past 10 years, particularly in connection with the development of satellite and high-altitude rocket launching techniques. The number of methods used for this purpose has greatly increased. As a result, the amount of information on the ionosphere has greatly increased and a more detailed study of its fine structure and of the phenomena occurring in it has become possible. Previously, such studies were concerned mainly with the lower portion of the ionosphere (D-, E- and F-regions) with the aid of radiowaves which, depending on their frequency, are reflected from different altitudes or propagate in the near-Earth waveguide formed between the Earth's surface and the "base" of the ionosphere. Studies of the outer ionosphere actually began after the launching of the first artificial Earth satellite. Since that time, most of the data known to us concerning this portion of the near-Earth plasma have been obtained and a large number of such data proved to be unexpected.

It is necessary to emphasize three main trends in the experimental study of the outer ionosphere that have been developed during the past 10 years.

The first trend includes various tests carried out with satellites. These aggregate tests involve the use of satellite measurements of various parameters of the ionosphere by means of different types of probes (Langmuir probes, mass spectrometers, impedance probes, particle traps), by means of pulsed ionospheric radio stations aboard satellites, by means of radiowaves emitted from a satellite and received in the vicinity of the Earth (method for determining the difference of Doppler frequency shifts on coherent radio frequencies, method of Doppler's rotary effect, otherwise known as the Faraday effect, analysis of radio wave amplitudes, etc.).

The second trend includes tests involving measurements of intensity and determination of energy spectra of radio waves incoherently scattered on fluctuations of the concentrations of electrons in the ionosphere. In order to carry out such tests, the use of antennas

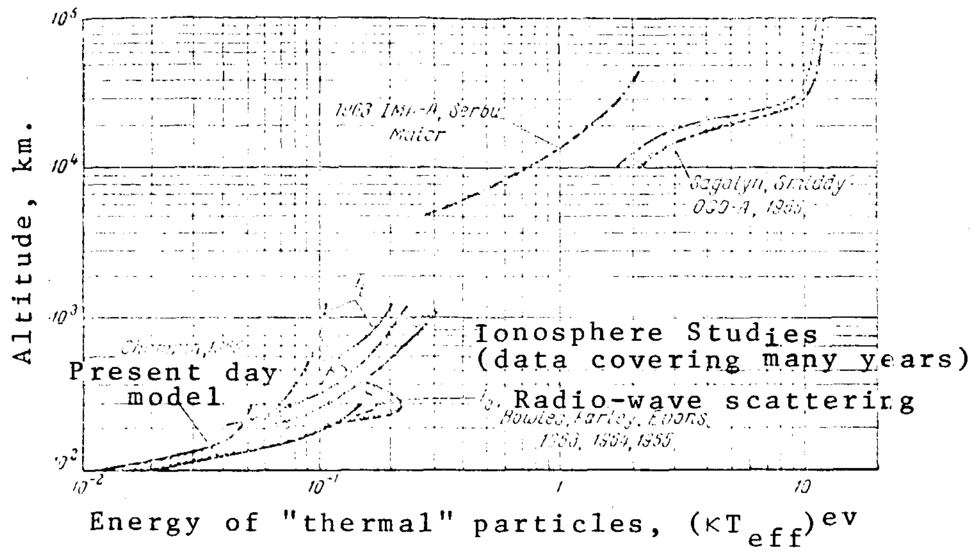

Fig.2.

with a large effective emittance area and powerful emitters in the ultra-short-wave radio frequency band is required.

The third trend includes the study of various properties of low-frequency waves (for example, electron and ion whistlers) propagating in the ionosphere and emitted by external sources (lightning discharges, long-wave radio stations) or excited in the ionospheric plasma. These studies include observations on the surface of the Earth, where only transverse waves can be recorded; these are channeled in the ionosphere by the magnetic field and by elongated inhomogeneous formations. Direct observations on satellites, where longitudinal oscillations and plasma-emitted waves are also recorded, play a considerable role in such studies.

All of the aforementioned trends are quite effective and they require a thorough and detailed theoretical processing of results, thus making it possible to simultaneously extract from primary experimental data the information on various parameters of the ionosphere. For example, from the same experimental data in low-frequency tests or with the aid of incoherent radio wave scattering it is possible to determine the electron concentration as a function of altitude, the temperature characteristics of electrons and ions, the ion composition at various altitudes, i.e. it is possible to obtain a wealth of information. Naturally, when a number of results obtained by different methods are compared, their reliability is greatly increased and they can be checked.

Following are some of the basic properties of the outer ionosphere that have been established in recent years.

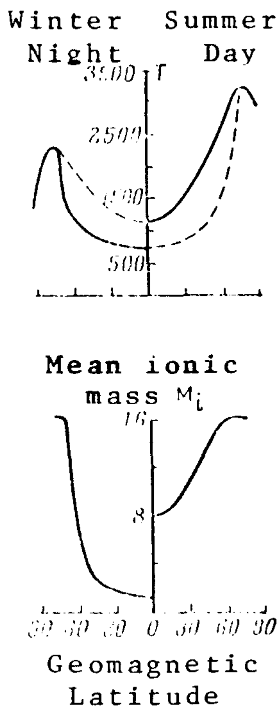

Fig.3.

The average concentration N_0 of charged particles (electrons and ions) in the outer ionosphere decreases slowly and smoothly with the altitude. At an altitude $z \sim 1000$ km $N_0 \sim$ $\sim$ $(3-8)10^4$ electrons/cm^3. At $z \sim 6000$ km, $N_0 \sim (2-8)10^3$ el/cm^3, and at $z \sim 10,000-15,000$ km, $N_0 \sim 10^3$ el/cm^3 and higher. We may see that the high electron concentration extends to great distances from the surface of the Earth (Fig.1).

In the altitude region of 15,000 to 25,000 km, the properties of near-Earth plasma have not yet been studied to a great extent. Here, complex processes are observed: for example, the so-called "knee" is formed. In this region the electron concentration drops very rapidly, almost in a jump-like fashion; under certain conditions, with an increase in altitude of only 600-700 km it is reduced by several tens of units and varies within the limits of $N_0 \sim (2-5)10^2$ el/cm^3 to $N_0 \sim 10-20$ el/cm^3. For a number of reasons this is precisely the region of the outer ionosphere that apparently defines the upper boundary of the ionosphere. Above it the nonstationary state of the ionosphere is intensified, the value of the electron concentration is probably unstable (see Fig.1), electric fields increase in size, and the quasi-neutrality is greatly disturbed.

It was found that above 1000-1200 km the ionosphere consists mainly of protons, i.e. ions of atomic hydrogen. Helium is also present and its relative content is only $(1-2)10^{-2}$.

The behavior of helium is rather puzzling since it disappears during certain periods. Below 300-700 km the main component of the ionosphere consists of positive ions of atomic oxygen.

The temperature of "thermal" ionized particles increases greatly with altitude. At an altitude $z \sim 1000$ km, the temperature corresponds to about $(1-3)10^{-1}$ ev $(T = 1000-3000°\ K)$. At an altitude $z \sim 10,000$ km, $\kappa T \sim 1-2$ ev $(T = 10,000-20,000°\ K)$. In the "knee" region, κT is of the order of several electron-volts, while above approximately 30,000 km the temperature, apparently, changes slowly and corresponds to $\kappa T \sim 10$ ev (Fig.2).

Recently, characteristic relations have been obtained between the magnetic latitude and the ionic mass M_i and the temperature T. In the region of altitudes of 700-800 km and somewhat higher (no data are available for higher altitudes) the value of M_i drops rapidly; starting from a geomagnetic latitude of about 60° the ionic mass varies from $M_i = 16$ (oxygen ions) to $M_i = 1$ at night during winter and to $M_i = 8$ during the day in summer near the geomagnetic equator. The temeperature in this latitude range drops from $T \sim 2500-3000°$ K to $T \sim 800-1200°$ K (Fig.3). Thus, at the above latitudes, near the geomagnetic equator, a belt of light particles of lower energy is probably formed; this is linked with the effect of the magnetic field on their distribution in the outer ionosphere.

Plasma oscillations and plasma waves of various types are frequently excited in the outer ionosphere. Gyroresonances, resonances on hybrid and Langmuir frequencies, and Čerenkov radiation are observed. Apparently, these waves frequently arise in the form of packets covering a relatively broad frequency range. The frequency range changes several times relative to the central frequency of the packet, There is evidence that longitudinal ionic-acoustic waves and hybrid superlow-frequency waves in the kilohertz frequency range are also excited. Plasma-emitted SLF-waves are also observed.

Frequently excited in the outer ionosphere are packets of ULF (ultra-low-frequency) waves with a frequency ranging from several hertz to fractions of a hertz. Only transverse ULF waves have been observed.

SLF and ULF waves probably arise in plasma as wave packets excited in a limited plasma cluster or a plasmoid moving along magnetic tubes. A number of data are available which indicate that waves are excited by a "trigger mechanism" type of action: they are generated when an external electromagnetic field is present in the ionosphere (waves of a whistler or of a low-frequency radio station, etc.).

The aggregate of data presented in this article give only a limited and schematic characteristic of the outer ionosphere, on whose properties extensive information is already available in the literature. In many respects, this information has not been assimilated; it is not understood and it has not been sufficiently checked. However, the present author still hopes that this brief article shows what role the investigation of the ionosphere plays in the study of the Sun and what have been the achievements in this field during the past few years.

*** THE END ***

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Volt Technical Corporation
1145 19th Street, N.W.
Washington, D.C. 20036
Telephone: [202] 223-6700 X-36,37.

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ALB/ldf